PIK

## Elena Surovyatkina

*Potsdam Institute for Climate Impact Research (PIK)*

# New approach pushes limits of numerical weather prediction

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety
B-EPICC project
18_II_149_Global_A_Risikovorhersage

INTERNATIONALE
KLIMASCHUTZINITIATIVE (IKI)

16 August, 2022, Lima, Peru

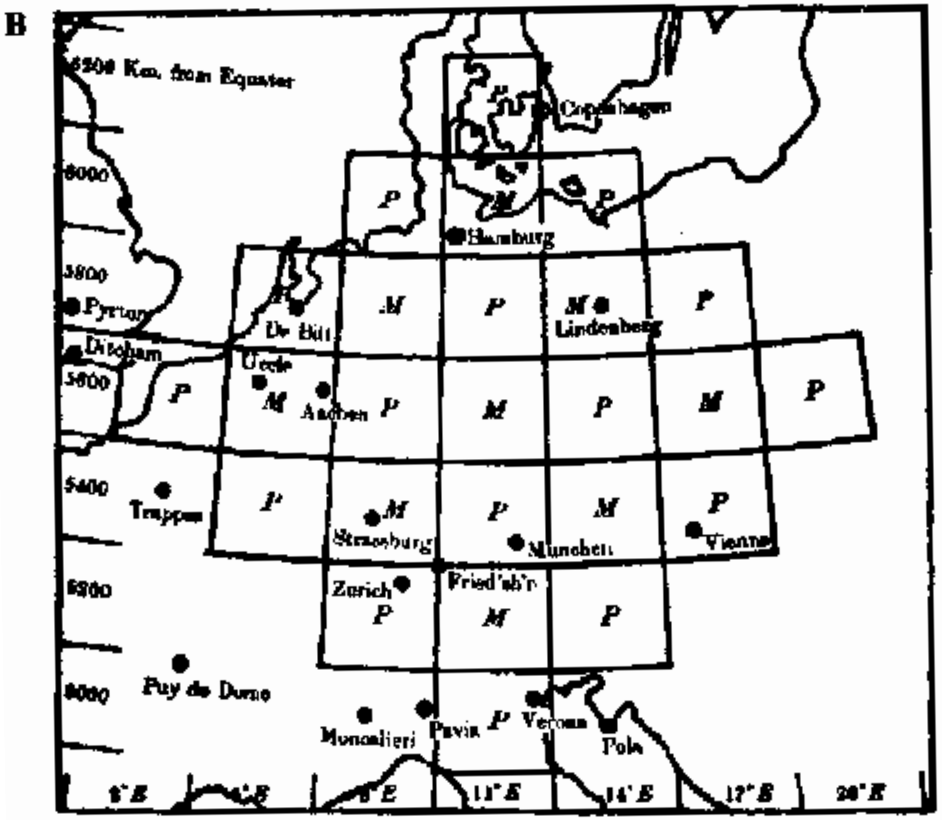
# Contents

- Major limitations in numerical weather prediction
- The main principles of the prediction of monsoon timing
- Future perspective for the extension of monsoon forecast worldwide.

‘‘Perhaps someday in the dim future, it will be possible to advance the computations faster than the weather advances. … But that is a dream.“ 1922

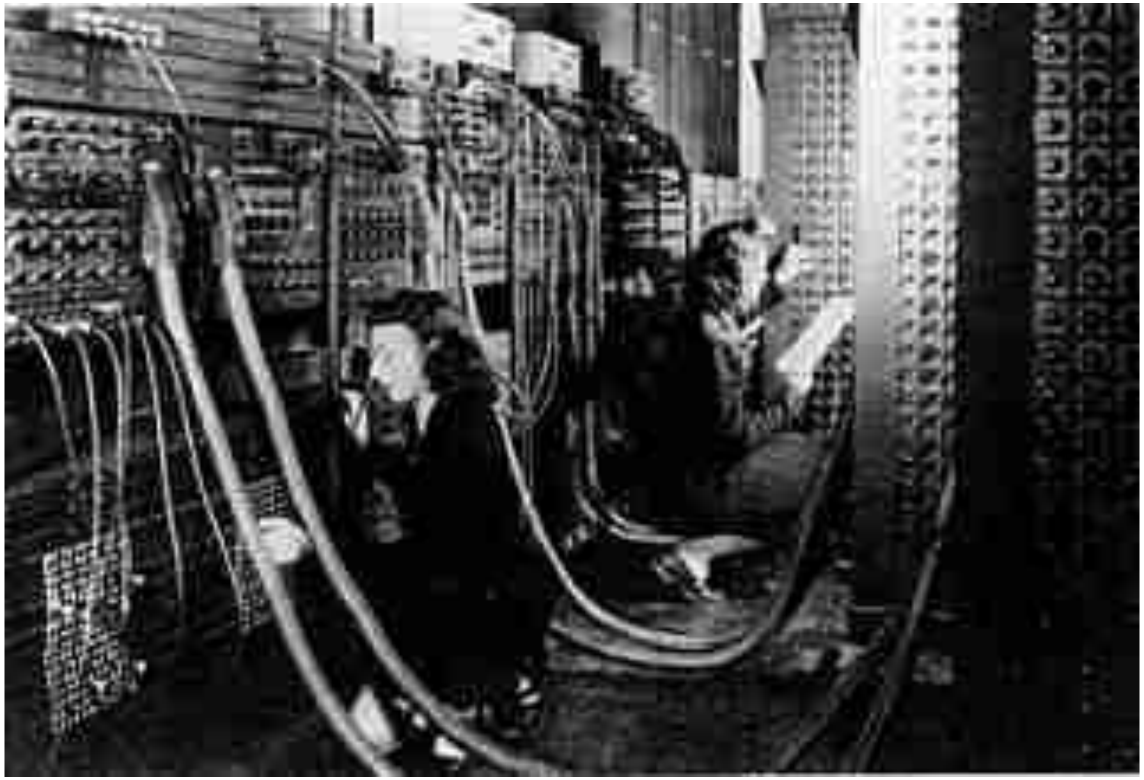
Lewis Fry Richardson
11 October 1881 – 30 September 1953

A six-hour weather forecast for two points
in Central Germany 20 May 1910



Richardson, L.F.: Weather Prediction by Numerical Process. Cambridge University Press, Cambridge (1922)

# The first calculations for a 24-hour forecast took ENIAC nearly 24 hours to produce (1950)



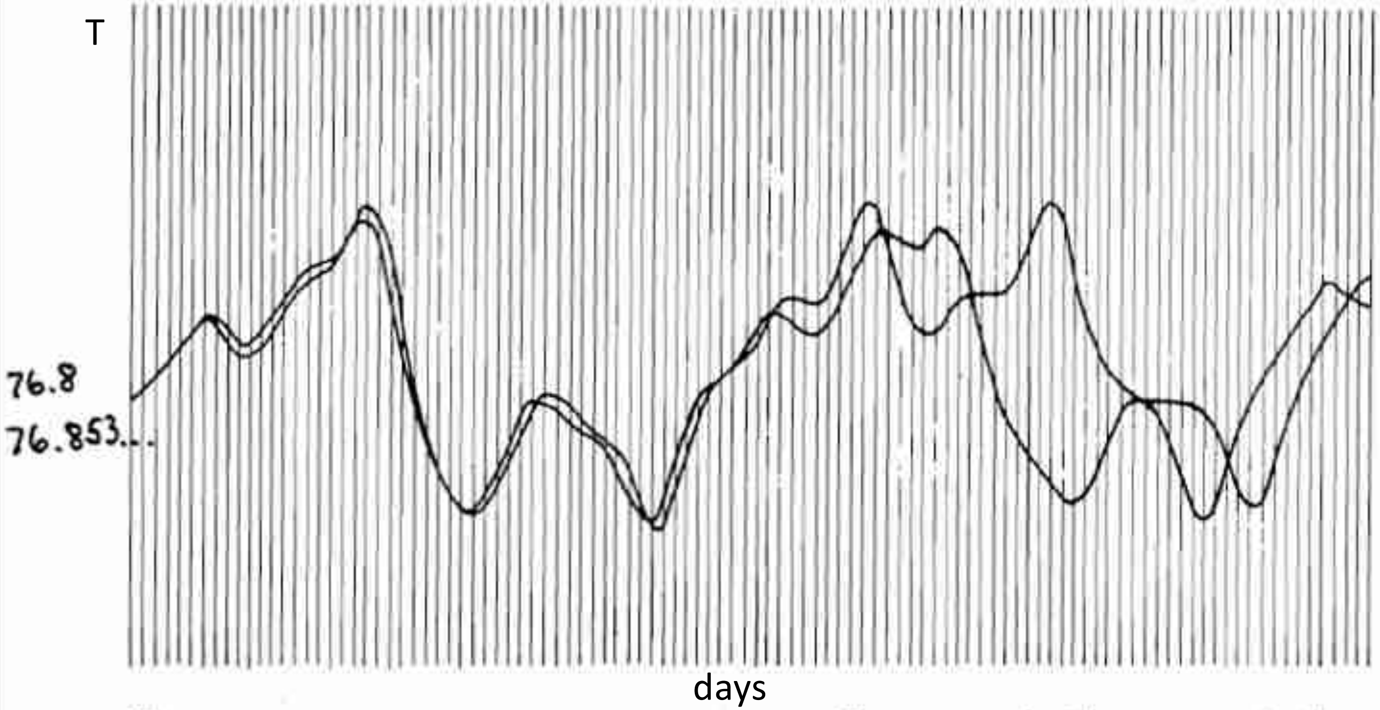
ENIAC Programmers, 1943-1945:
*Gloria Ruth Gordon [Bolotsky] and Ester Gerston*

A group of female “computers” was instrumental in building the ENIAC during World War II.

# Butterfly effect: “When a butterfly flutters its wings in one part of the world, it can eventually cause a hurricane in another.”

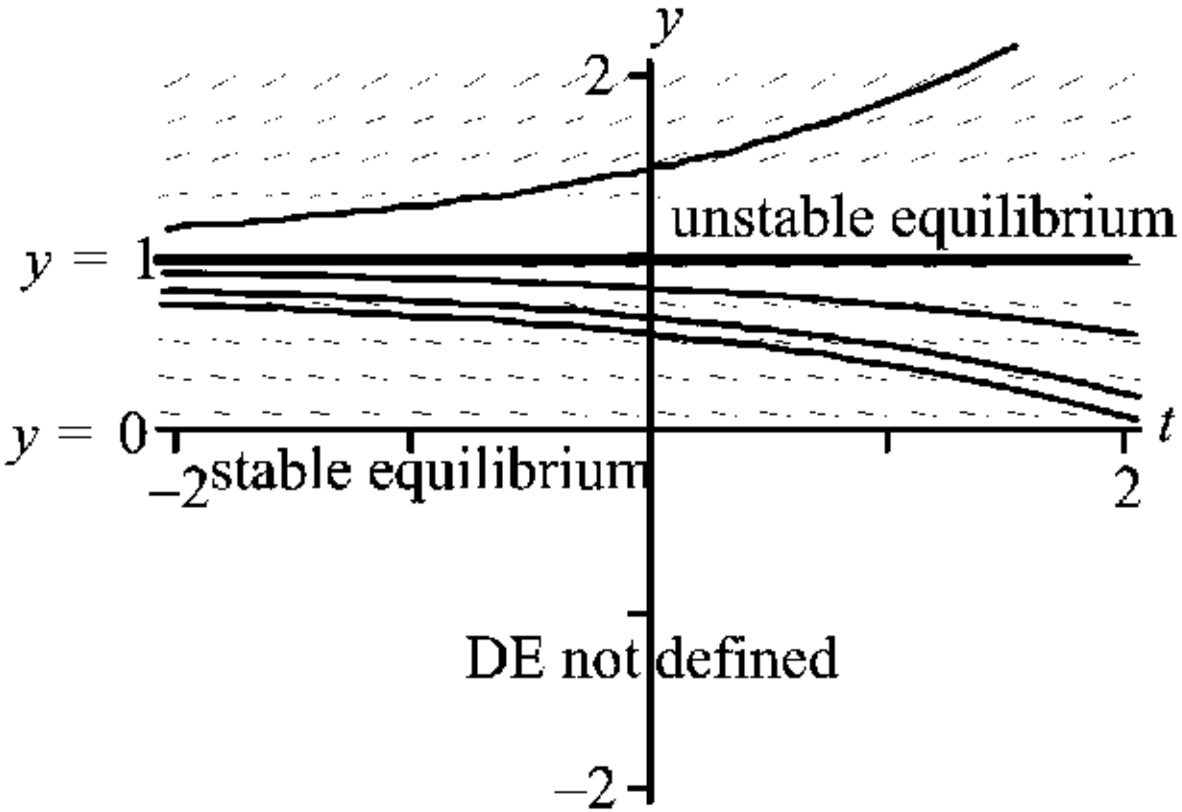
Edward Norton Lorenz
May 23, 1917 – April 16, 2008

A small change in initial conditions had created a significantly different outcome.



HOW TWO WEATHER PATTERNS DIVERGE. From nearly the same starting point, Edward Lorenz saw his computer weather produce patterns that grew farther and farther apart until all resemblance disappeared. (From Lorenz's 1961 printouts.)

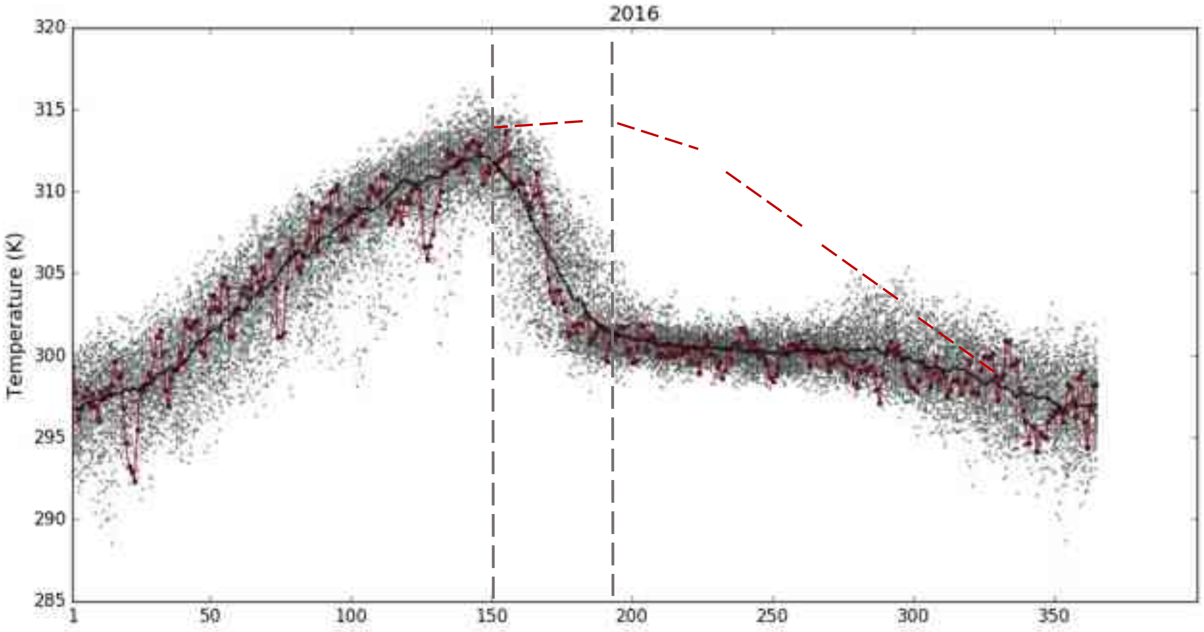
# Unstable solution



# A fundamental problem in numerical weather prediction

A fundamental problem lies in the chaotic nature of the spatial differential equations used to simulate the atmosphere. It is impossible to solve these equations exactly, and **extremely small errors in temperature, wind, or other initial inputs grow with time - double every five days**,[Cox, John D., 2002] making it **impossible for long-range forecasts.** Therefore, numerical weather prediction methods only obtain an approximate solution.

Abrupt transition



Daily mean near-surface air temperature over the Eastern Ghats (1950-2020)

The numerical weather model **cannot reproduce the abrupt transition** common in the tropics.

# Major limitations in numerical weather prediction

- Numerical Weather Prediction has a limit to forecast the weather for **up to 5 days** in the future.
- Existing observation networks have poor coverage in some regions (for example, over the Pacific Ocean), which introduces uncertainty into the true initial state of the atmosphere. These uncertainties limit forecast model accuracy to about **five or six days** into the future [Weickmann et al. 2001], [Chakraborty, Arindam, 2010 ].
- General Circulation Model (GCM) includes an inadequate description of basic processes like **cloud formation, moist convection, and mixing** is what climate models **miss most** [Stevens and Bony, 2013].
- «Use of high-resolution regional models to downscale **regional climate change** is questionable if the global models from which **lateral boundary conditions** are prescribed are **not realistic**»[J.Shukla at al, 2009]

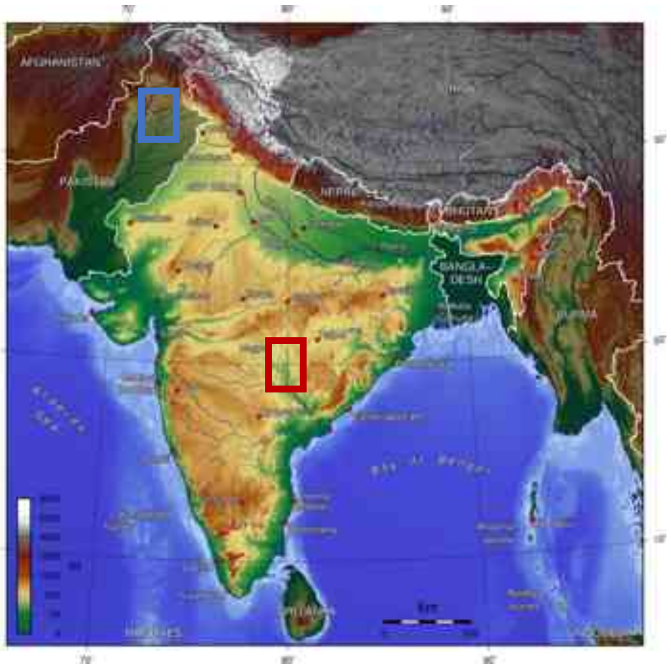
- **The limitations of current models prevent further progress**. A new strategy is desperately needed in weather and climate sciences [Stevens and Bony, Science 31 May 2013]

> Once we accept our limits,
> we go beyond them.

Albert Einstein

# Tipping Elements approach

The approach is fundamentally different from the numerical weather forecast; it is based on new spatial-temporal regularities (or teleconnection between Tipping Elements) and data analysis.



AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2016GL068392

# Tipping elements of the Indian monsoon: Prediction of onset and withdrawal

**Veronika Stolbova**[1,2,3,4], **Elena Surovyatkina**[1,5], **Bodo Bookhagen**[6,7], **and Jürgen Kurths**[1,2,3,8]

[1] Potsdam Institute for Climate Impact Research, Potsdam, Germany, [2] Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany, [3] Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia, [4] Department of Banking and Finance, University of Zürich, Zürich, Switzerland, [5] Space Research Institute, Russian Academy of Sciences, Moscow, Russia, [6] Institute of Earth and Environmental Science, University of Potsdam, Potsdam, Germany, [7] Geography Department, University of California, Santa Barbara, California, USA, [8] Institute for Complex Systems and Mathematical Biology, University of Aberdeen, Aberdeen, UK

**Key Points:**

- We identify geographic regions of critical behavior as tipping elements
- We use critical fluctuations in air temperature as a precursor of monsoon timing
- We improve the time scale of monsoon onset and withdrawal forecasting

**Supporting Information:**

- Supporting Information S1

**Correspondence to:**
V. Stolbova,
veronika.stolbova@pik-potsdam.de

**Abstract** Forecasting the onset and withdrawal of the Indian summer monsoon is crucial for the life and prosperity of more than one billion inhabitants of the Indian subcontinent. However, accurate prediction of monsoon timing remains a challenge, despite numerous efforts. Here we present a method for prediction of monsoon timing based on a critical transition precursor. We identify geographic regions—tipping elements of the monsoon—and use them as observation locations for predicting onset and withdrawal dates. Unlike

# What does the term 'tipping' mean?

One of the definitions of tip

- *overbalance or*
- *cause to overbalance*

*"The hay caught fire when the candle tipped over….."*

✓ The candle is an origin of the problem – *a tipping element of the system*.

✓ The time when the candle tipped over is *a tipping point*.

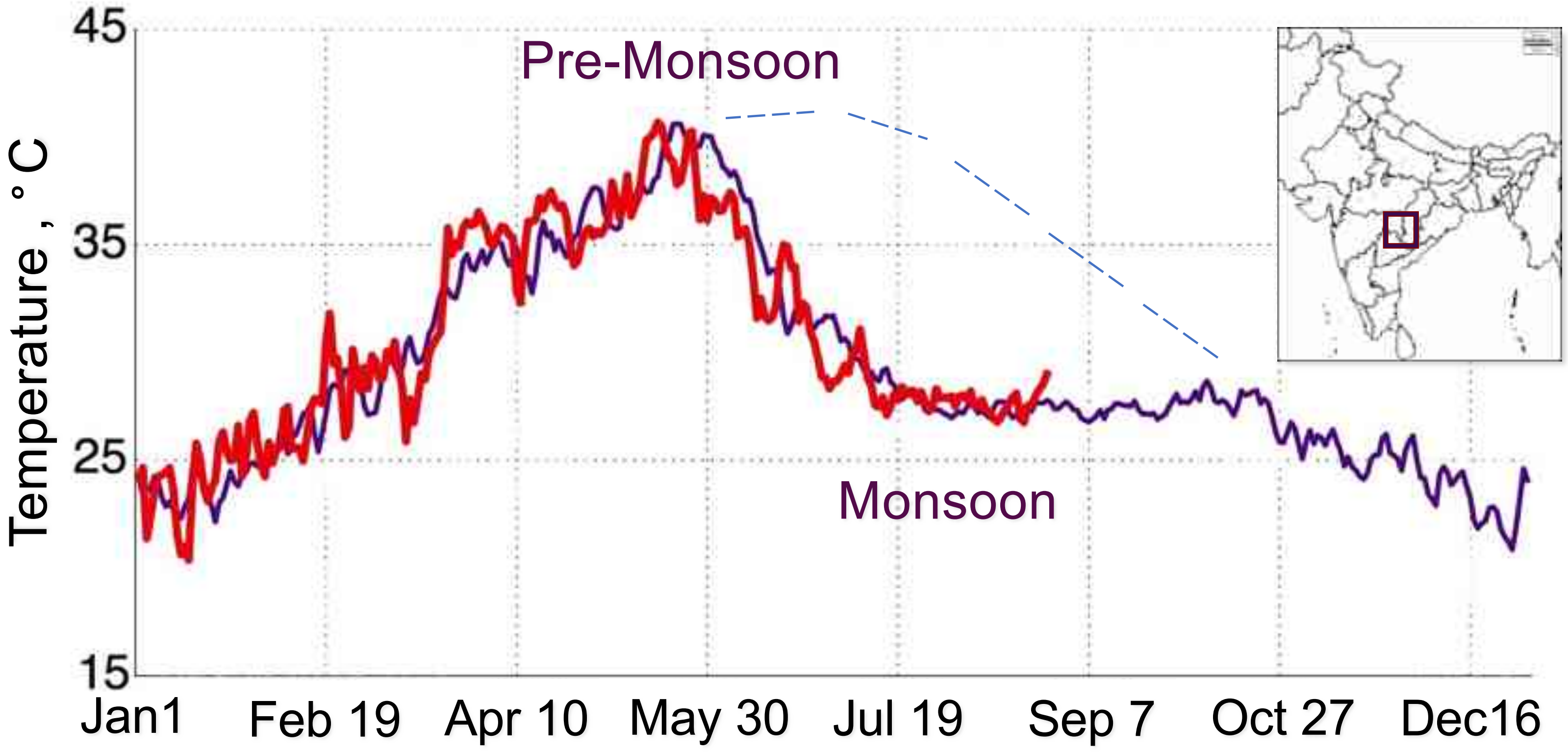
✓ An open window which gives the direction of flame propagation is the second *tipping element of the system*.

«The onset of monsoon… Is not a transition from a regime of no rain to rain; it is a transition from a regime of sporadic rainfall to spatially organized and temporally sustained rainfall…»

*critical*

R. Ananthakrishnan and M.K. Soman, 1990

# Is it a critical transition from pre-monsoon to monsoon?



- Where (geographically) do the critical conditions originate?
- How do the critical conditions propagate in space?
- How to predict a future transition?

# DATA

**NCEP/NCAR Reanalysis 1**

- 4-times daily, daily and monthly values for 1948/01/01 to present
- 2.5 degree latitude x 2.5 degree longitude global grid (144x73)

https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.surface.html

**ERA-Interim**

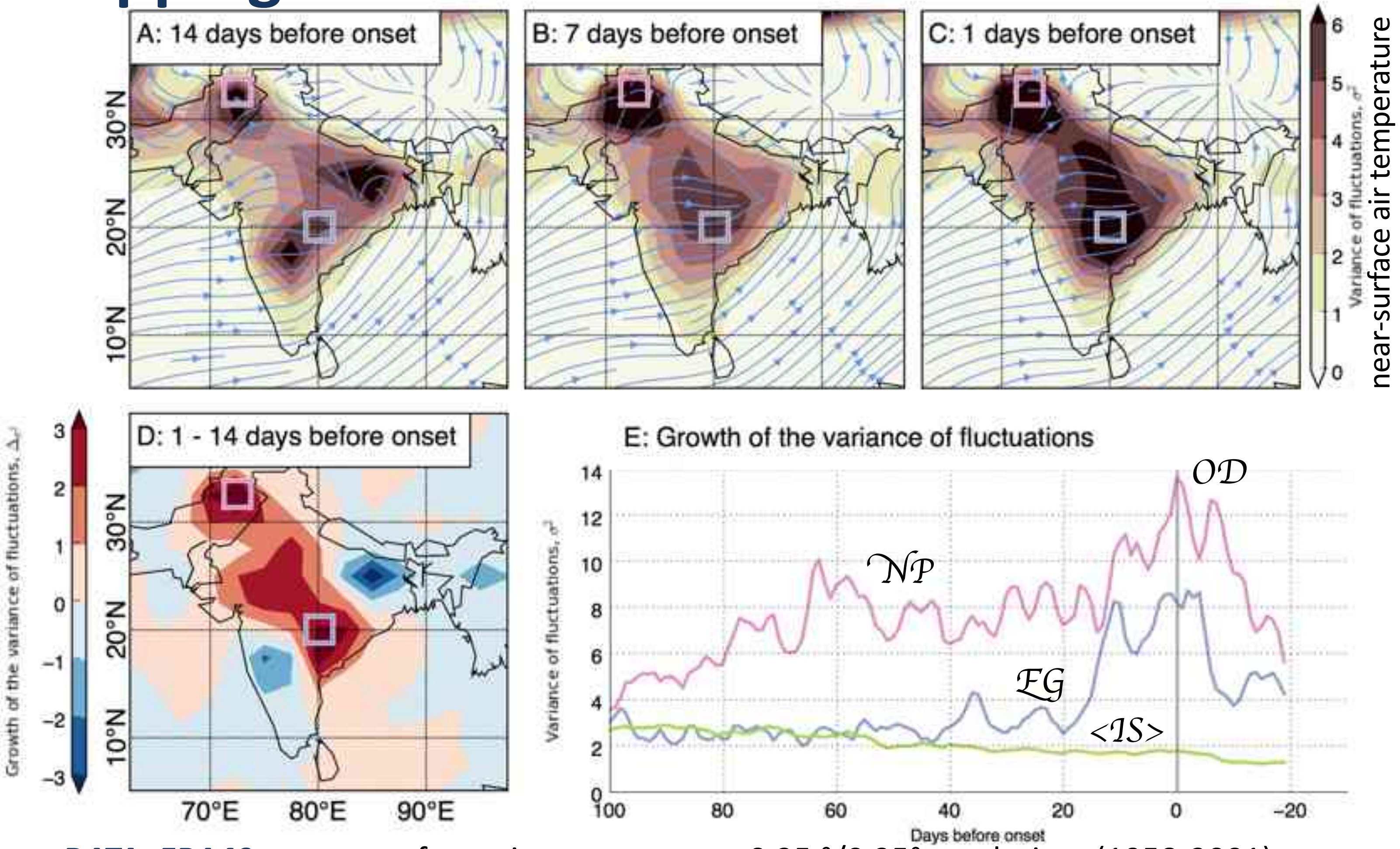
- 4-times daily, daily and monthly values for 1979/01/01 to present (delay 2m)
- 0.125 degree latitude x 0.125 degree longitude global grid

https://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era-interim

# The Indian Summer Monsoon

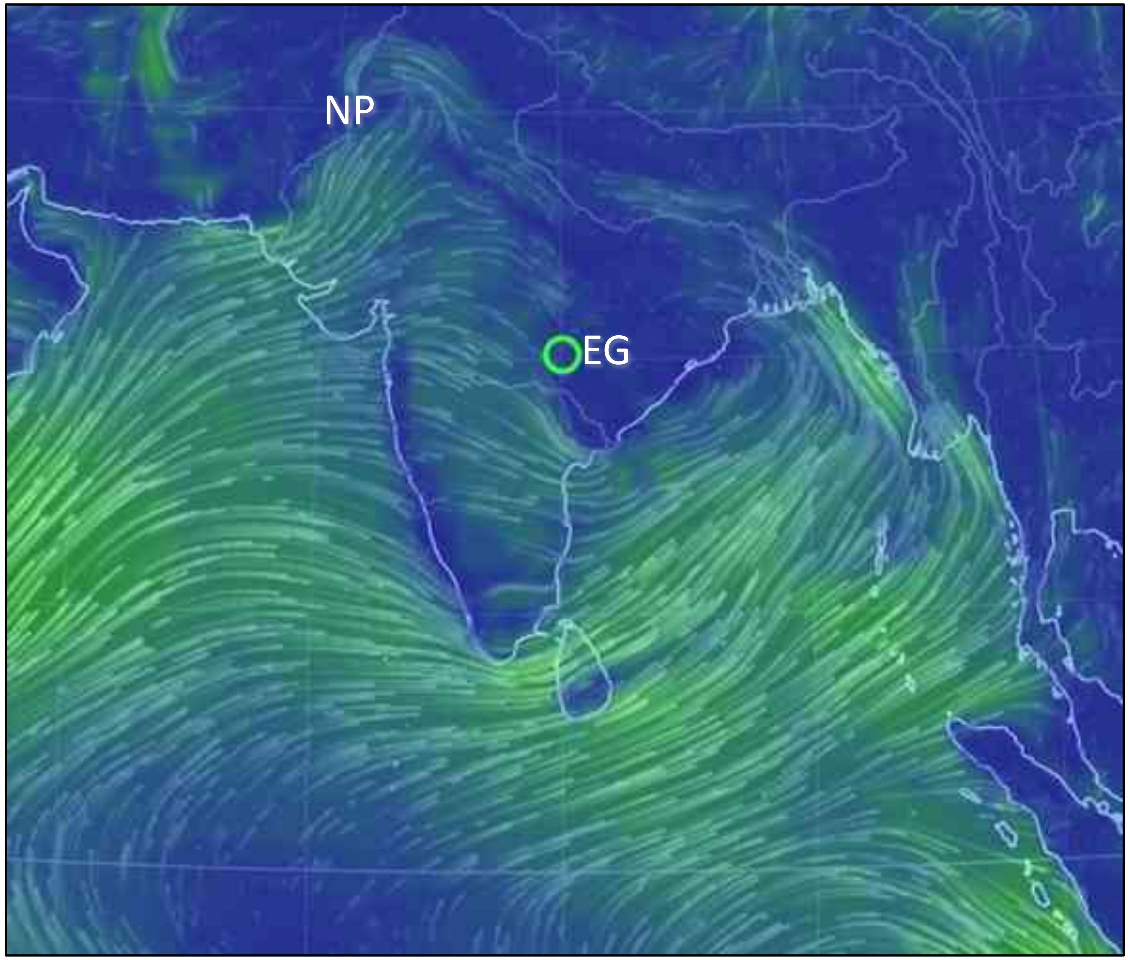
1. Where (geographically) do critical conditions originate?

# Tipping elements of Indian Summer Monsoon



***DATA: ERA40***: near –surface air temperature, 0.25 °/0.25° resolution, (1958-2001)

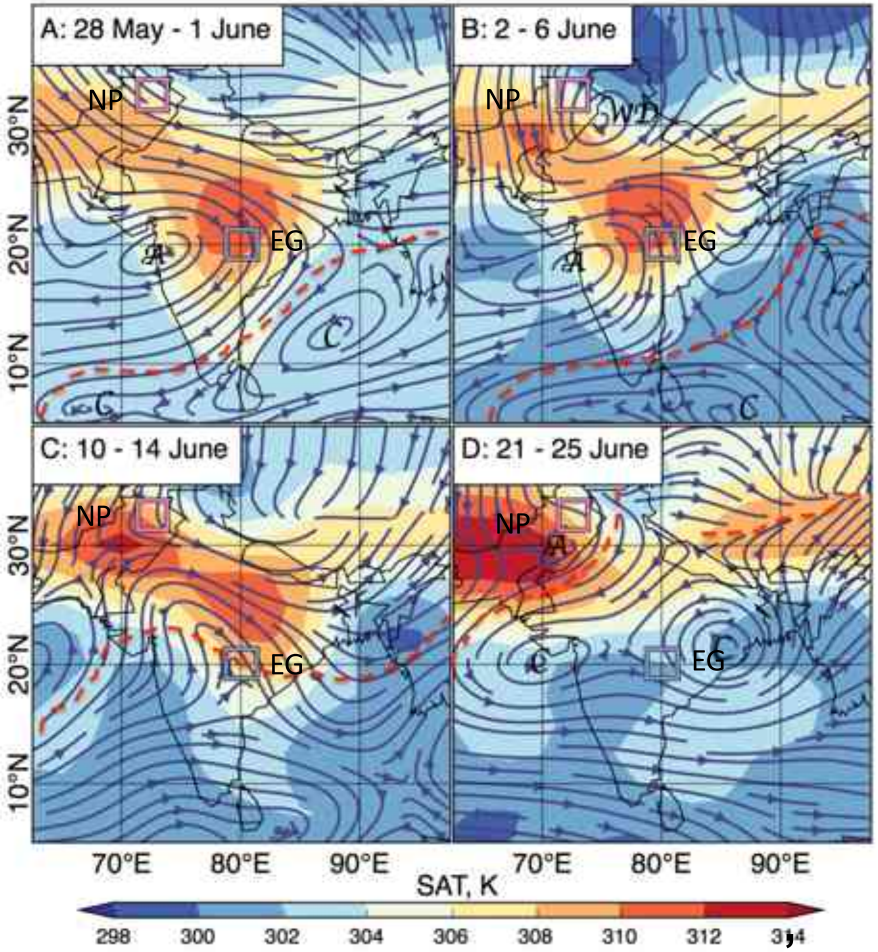
## 2. How do the critical conditions propagate in space?



https://earth.nullschool.net/#2016/06/17/0300Z/wind/isobaric/1000hPa/orthographic=78.74,8.05,626/loc=80,20

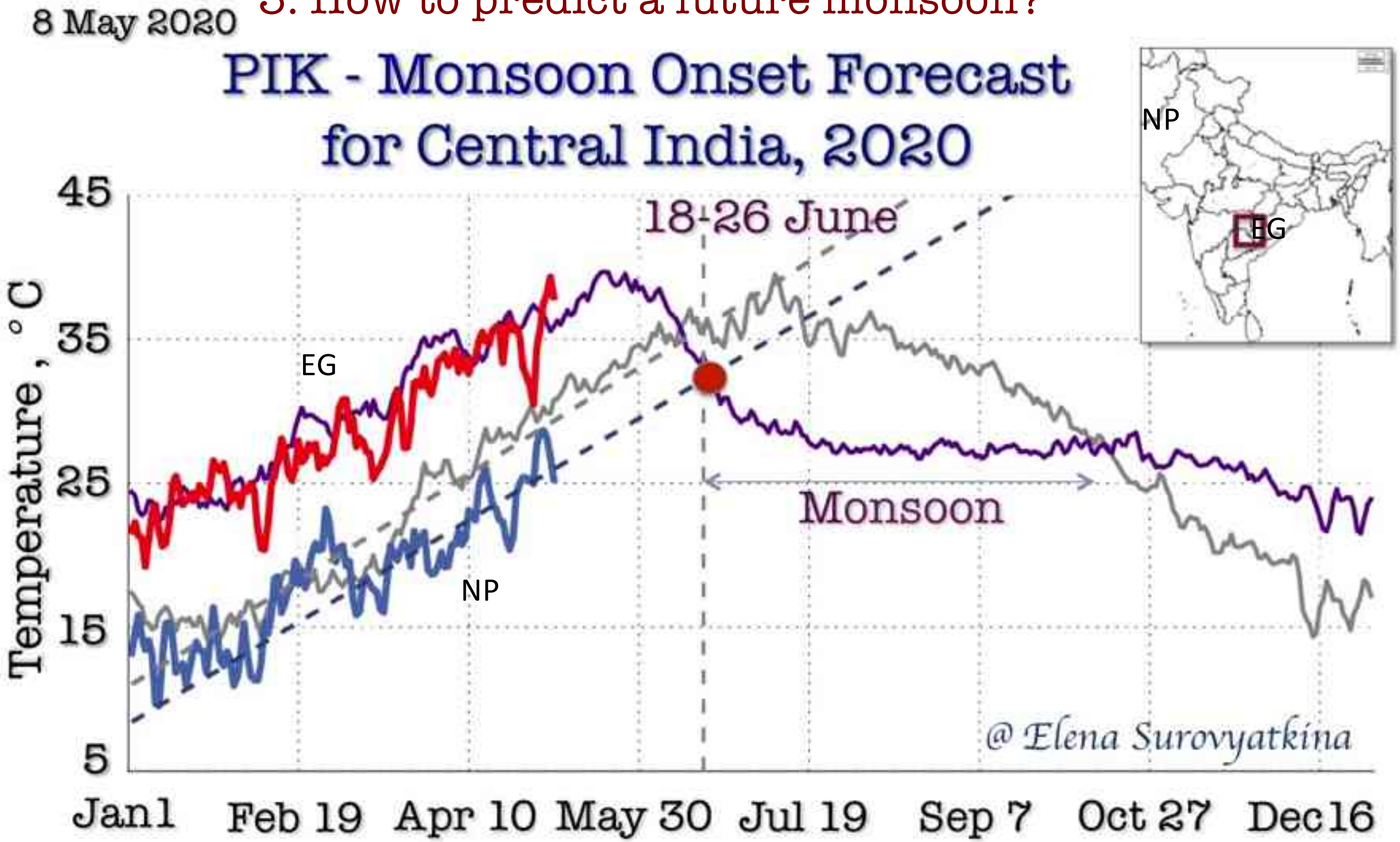
The onset of monsoon in the EG appears when the conditions in two regions NP and EG equalizes.

Temperature & wind fields

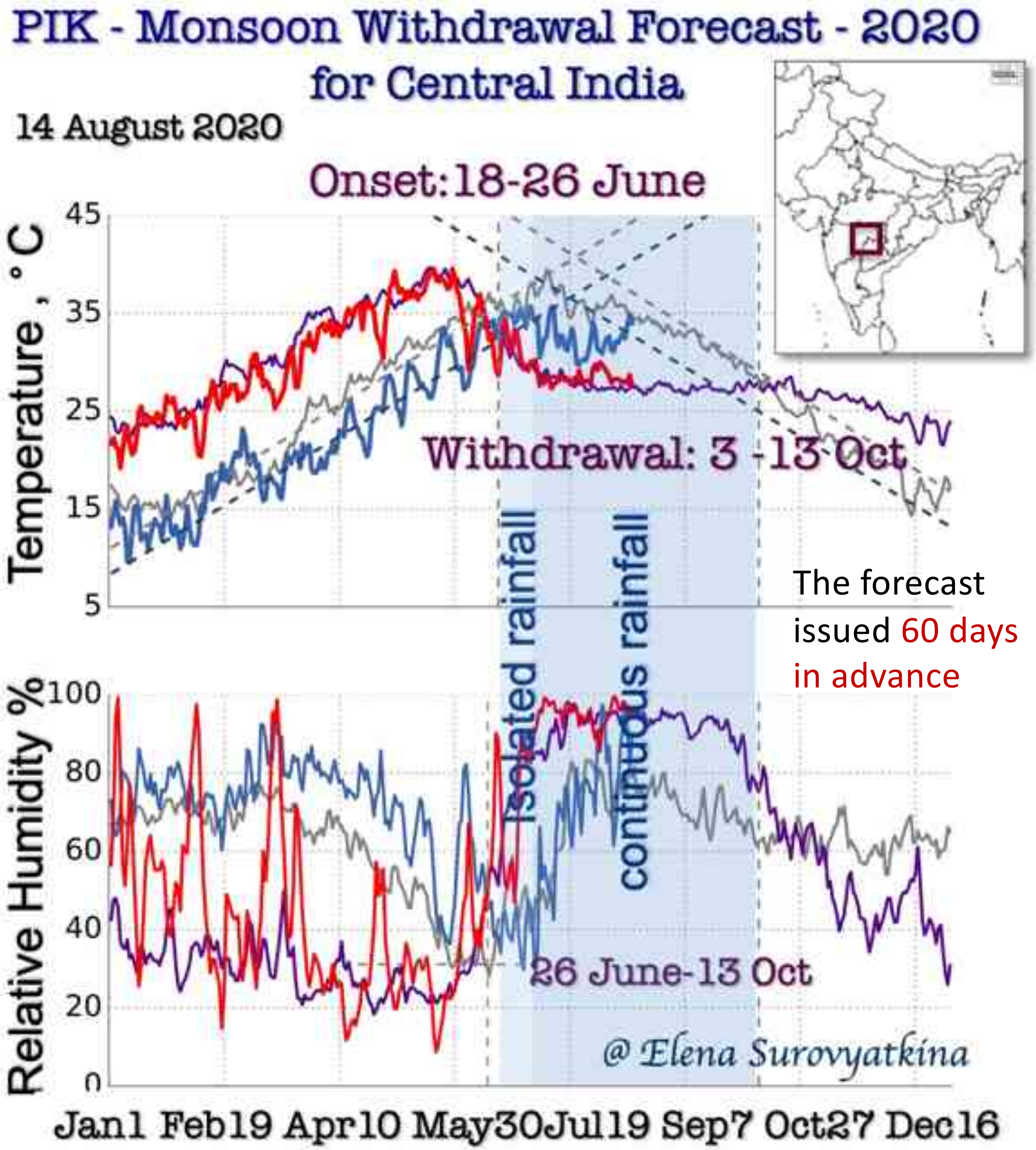


DATA: NCEP/NCAR reanalysis, 2.5°, near –surface air temperature, (1951-2015)

# 3. How to predict a future monsoon?



Daily mean near-surface air temperature till **May 8, 2020**, for the Eastern Ghats (red) and North Pakistan (blue). Violet and gray lines- past 5-years average for same regions. The tipping point (red) indicates the critical temperature and the forecasted onset date. The forecast issued 40 days in advance



The forecast issued 60 days in advance

Summer Monsoon 2020 in Central India began on the 26th of June.

The Indian Summer Monsoon (Southwest Monsoon) is likely to withdraw from the Central part of India (20N, 80E) between 3rd and 13th of October 2020.

Temperature anomaly in North Pakistan shrinks the duration of the monsoon season.

Nevertheless, after the monsoon withdrawal date in October, others post-monsoon rainfalls might appear over the central & northwest India.

# INDIAN SUMMER MONSOON FORECASTS (Central India, Eastern Ghats)

| | ONSET OF MONSOON | | WITHDRAWAL OF MONSOON | |
|---|---|---|---|---|
| Year | FORECAST<br>40 DAYS IN ADVANCE | OBSERVATION | FORECAST<br>70 DAYS IN ADVANCE | OBSERVATION |
| **2016** | 9-17 June | 17 June | 1-10 October | 10-12 October |
| **2017** | 14-22 June | 16-18 June | 7-17 October | 15-16 October |
| **2018** | 11-19 June | 9-19 June | 13-23 October | 18-21 October |
| **2019** | 10-18 June | 18-19 June | 14-24 October | 14-24 October |
| **2020** | 18-26 June | 26 June | 3-13 October | 7-13 October |
| **2021** | 21-29 June | 29 June | 31-10 October | 8-10 October |

https://www.pik-potsdam.de/en/output/infodesk/forecasting-indian-monsoon/welcome-to-the-pik-monsoon-page-1

# The South American Monsoon

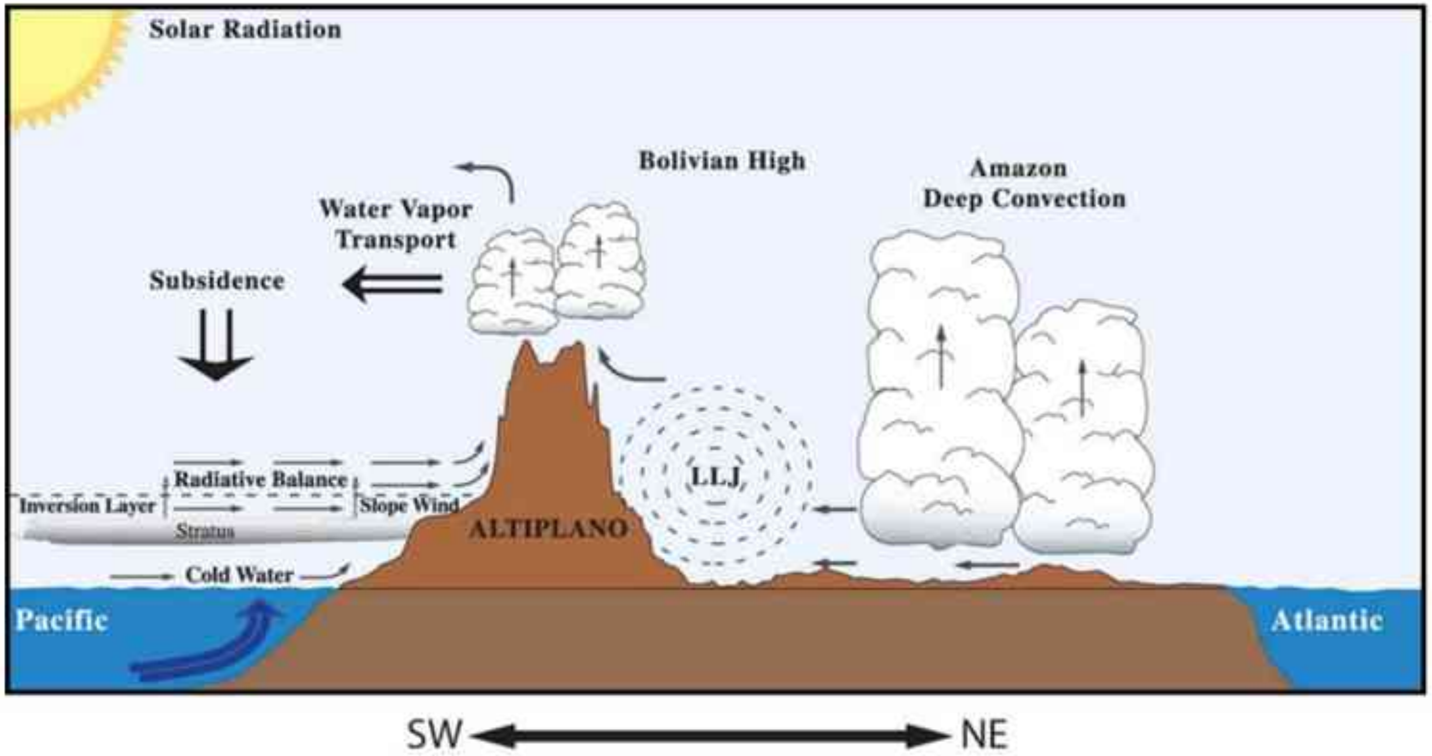


Fig. 4. Section across South America displaying schematically the major large-scale elements related to the South American Monsoon System. Source: Climate Variability & Predictability Program (CLIVAR)
(http://www.clivar.com/publications/other_pubs/clivar_transp/pdf_files/av_g3_0106.pdf)

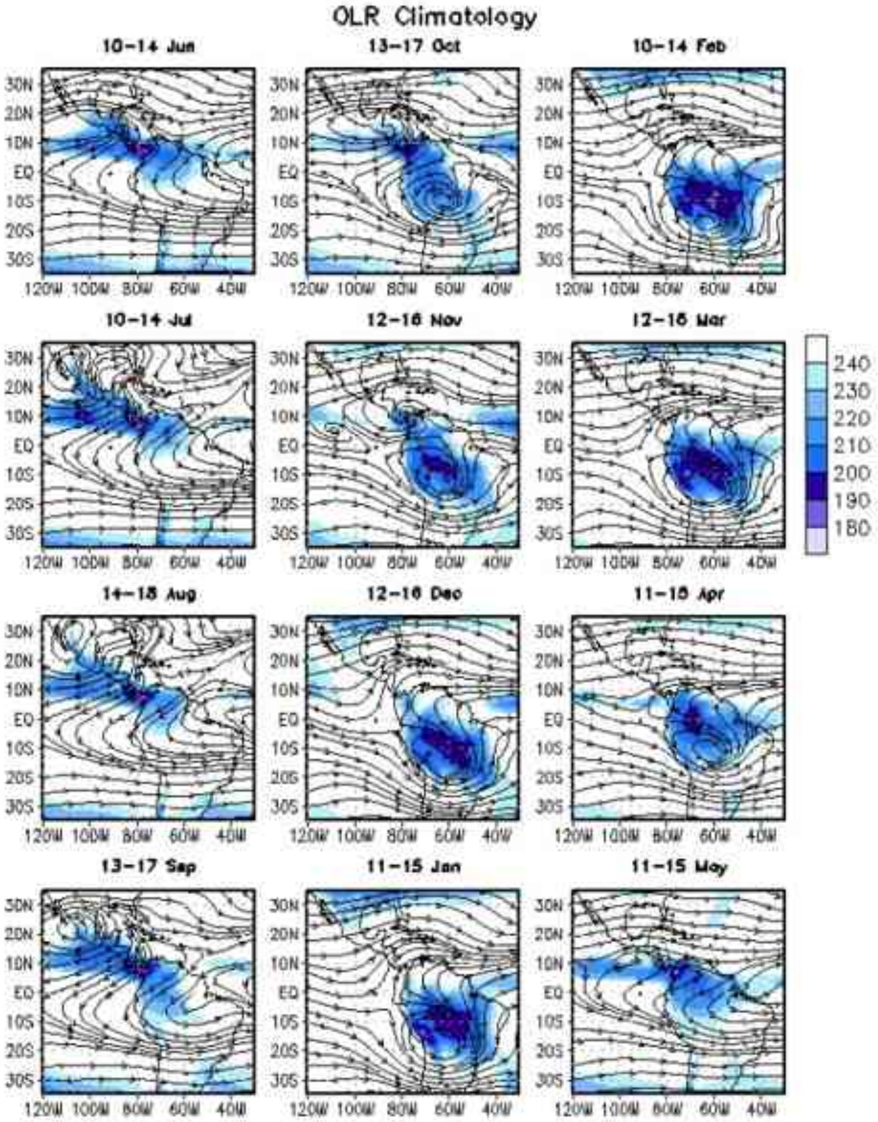


Fig. 8. Mean (1979-1995) seasonal cycle of OLR and 200-hPa streamlines. Units for OLR are W m-2. Low values of OLR indicate cold cloud tops (deep convection) in the Tropics.

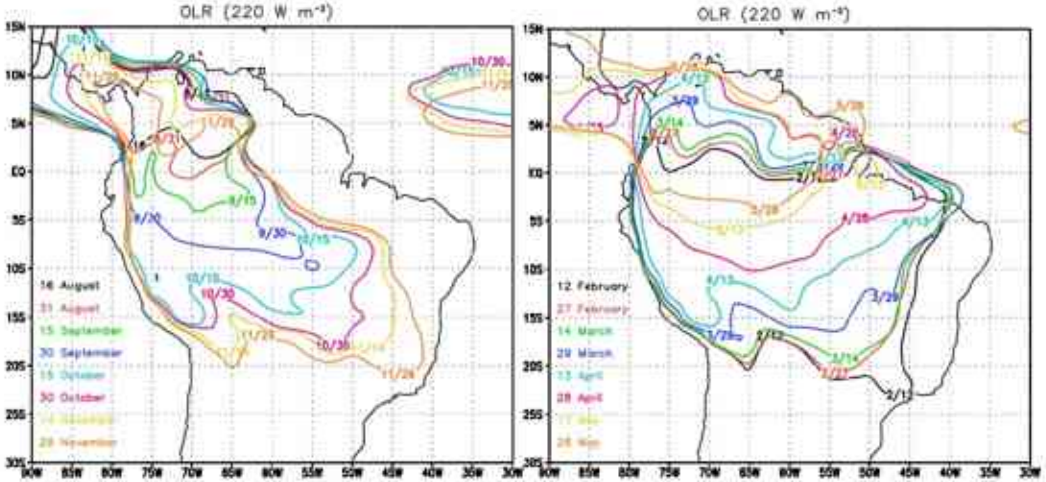
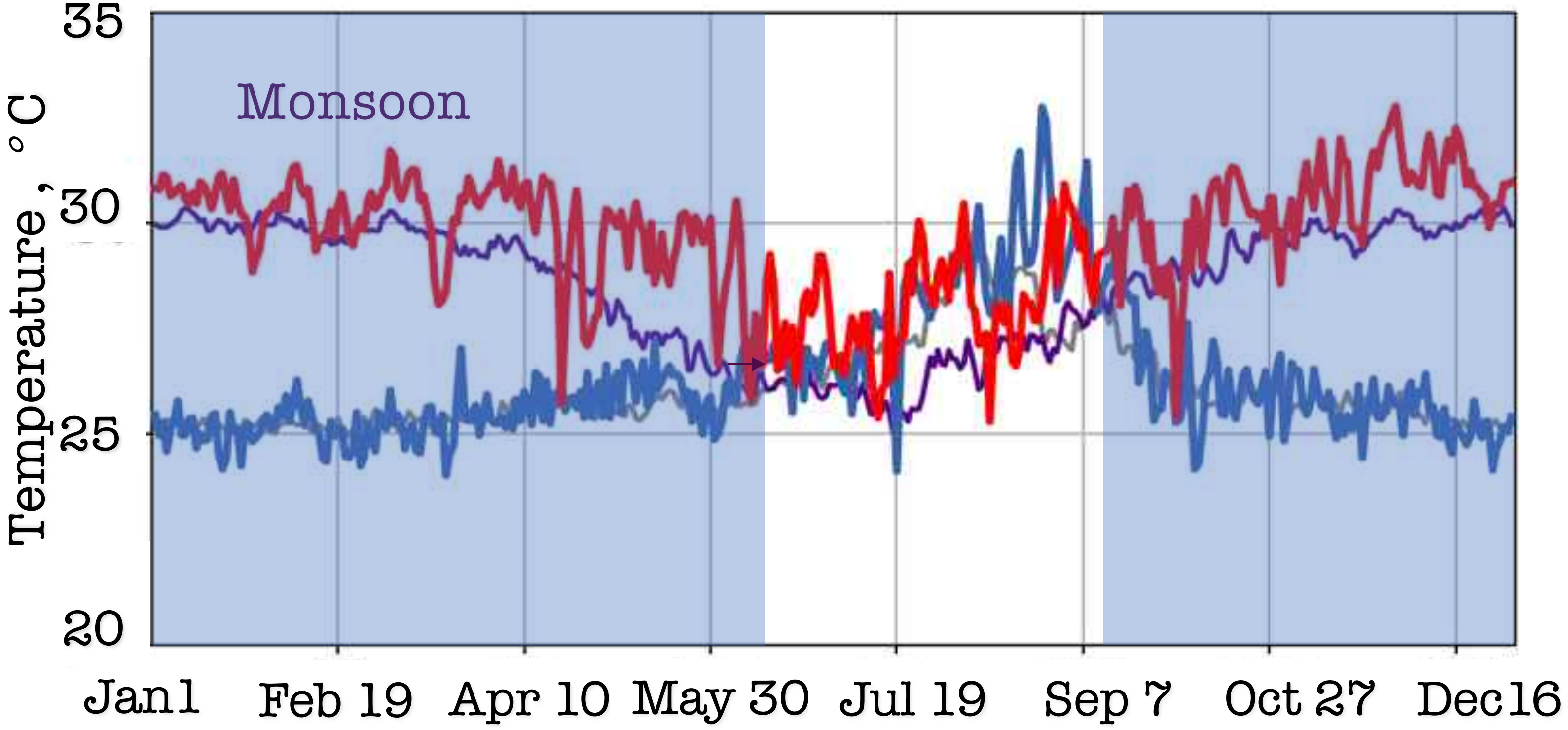


Fig. 10. Time onset and end dates for the wet season in the monsoon core region (Central Brazil) based on OLR less than 220 W m-2.

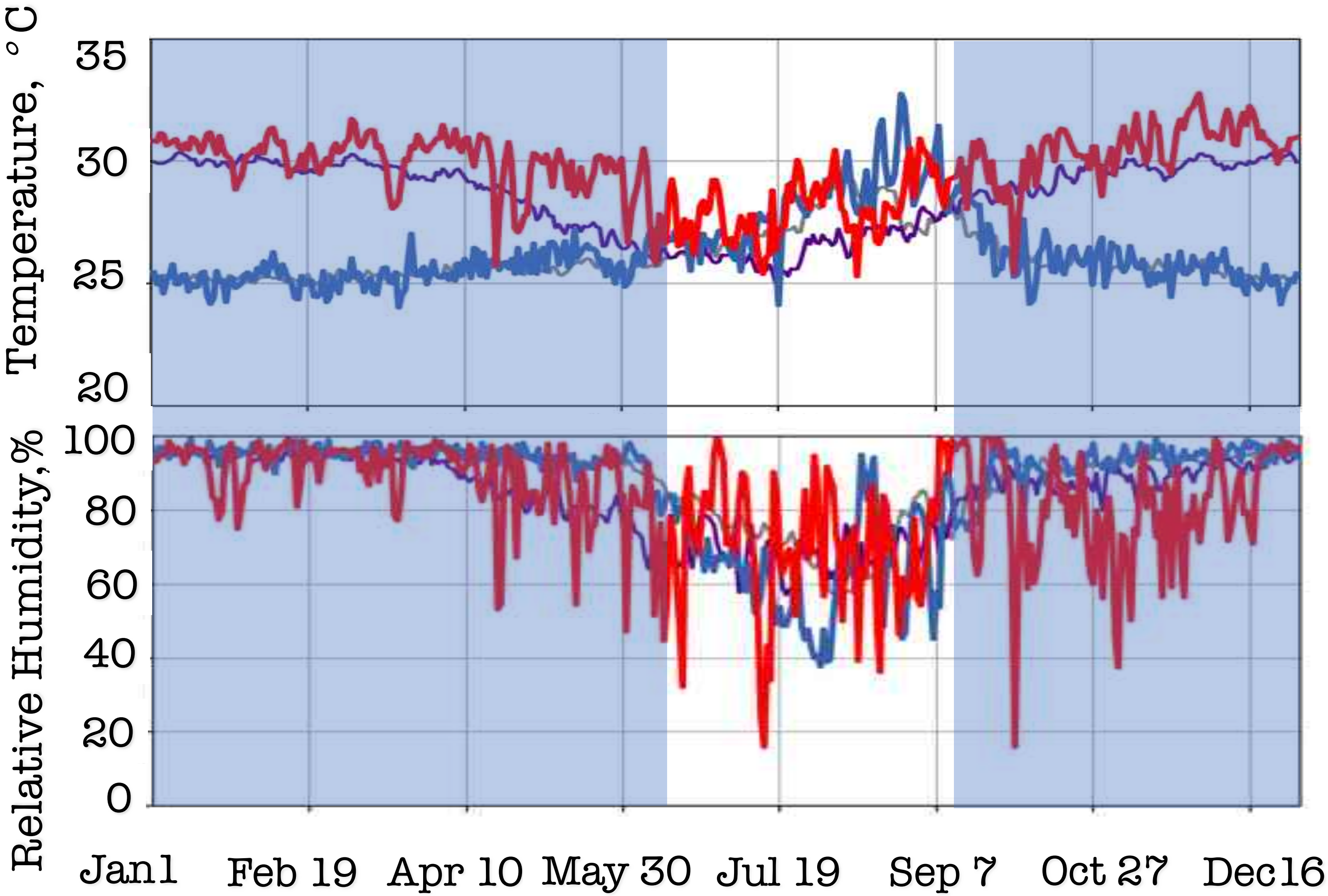
Vernon E. Kousky,; Viviane B. S. Silva,. The South American Monsoon System: Climatology and Variability. INTECH Open Access Publisher, 2012. Edition/Format: eBook

# South American Monsoon, Brazil, 2017



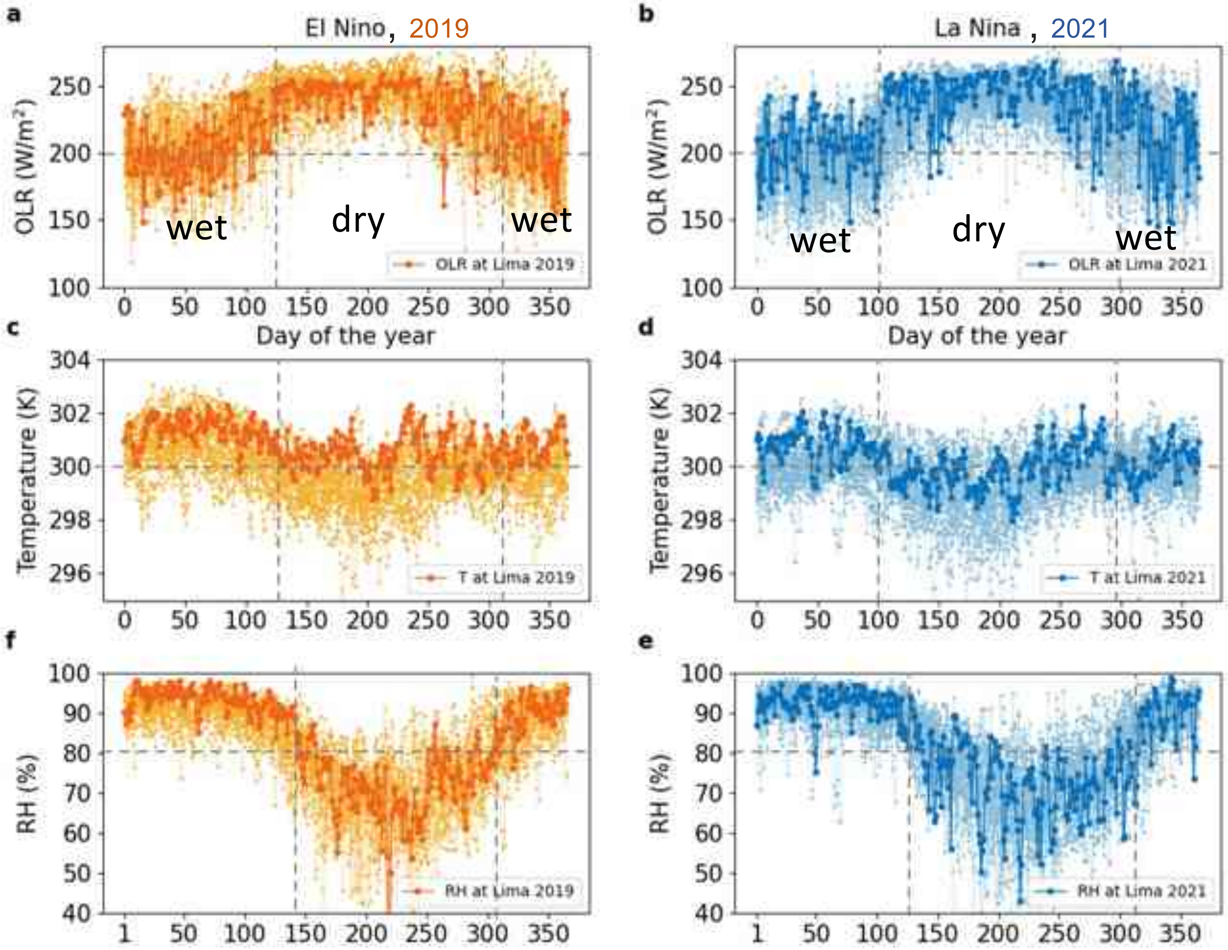
Daily mean near-surface air temperature **2017**, for two region in Brazil in Southeast (red) and Northwest (blue). Violet and gray lines- past 5-years average for same regions. The intersection indicates the critical temperatures of the beginning and end dates.

# South American Monsoon, Brazil,2017

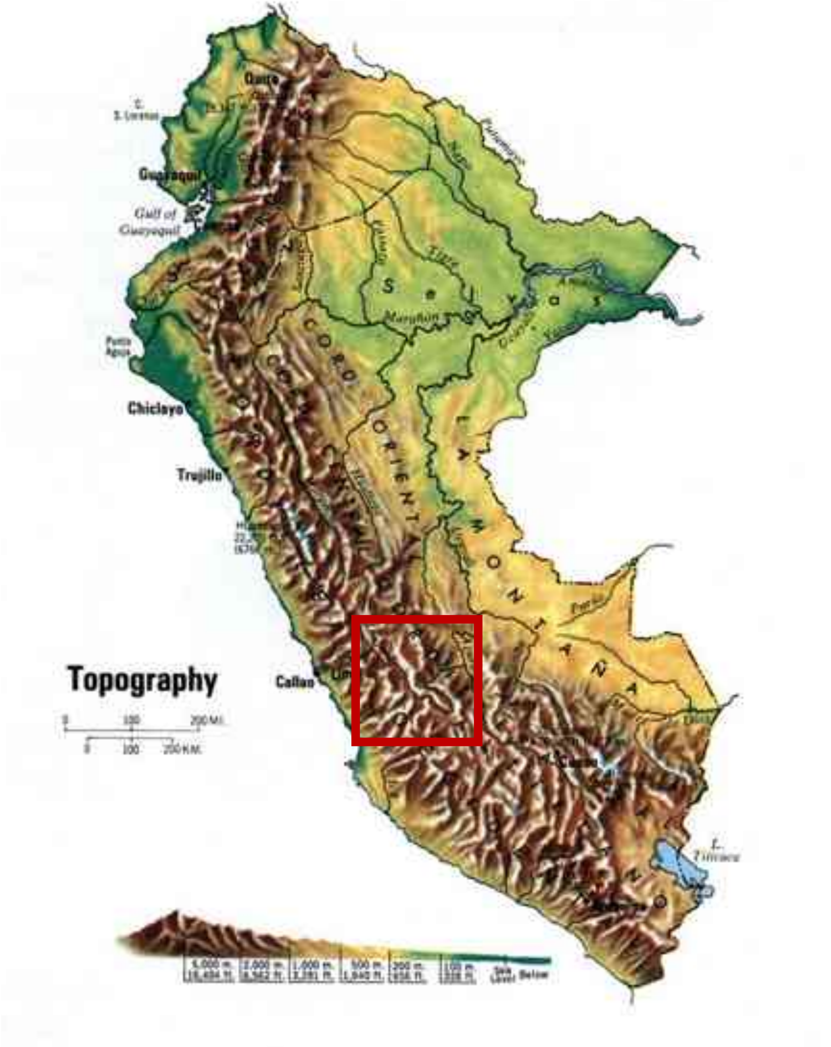


# Distrito de Izcuchaca (Huancavelica)

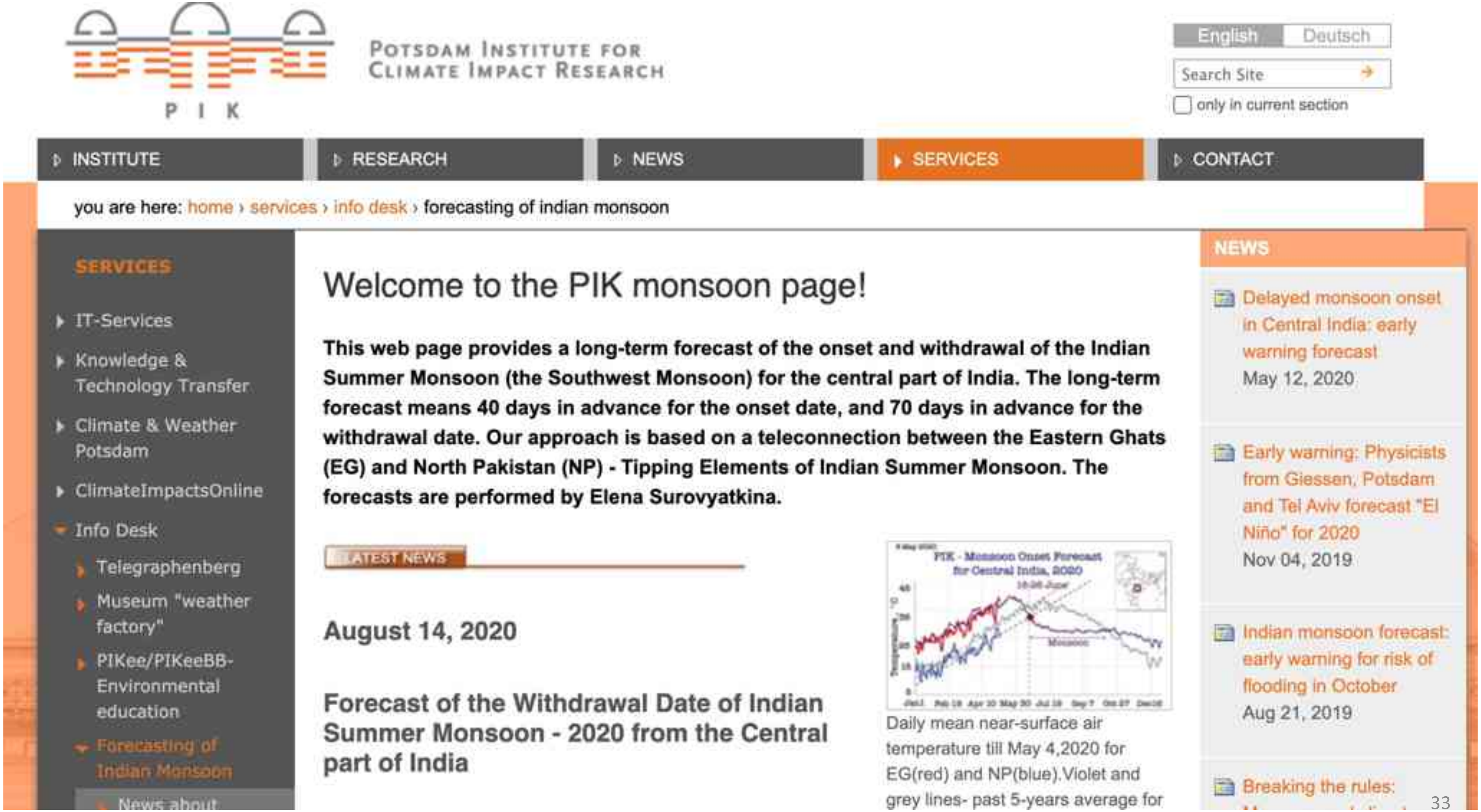
# Wet and dry seasons



NCEP/NCAR Reanalysis, 0.25 °/0.25°, 1000 hPa, 1975-2021



Central Peru: Lima, Huancavelica, Ayacucho, Ica, Junín. The square of 2.5°x2.5°, 12.5S, 75W https://www.pik-potsdam.de/en/output/infodesk/forecasting-indian-monsoon



# Welcome to the PIK monsoon page!

**This web page provides a long-term forecast of the onset and withdrawal of the Indian Summer Monsoon (the Southwest Monsoon) for the central part of India. The long-term forecast means 40 days in advance for the onset date, and 70 days in advance for the withdrawal date. Our approach is based on a teleconnection between the Eastern Ghats (EG) and North Pakistan (NP) - Tipping Elements of Indian Summer Monsoon. The forecasts are performed by Elena Surovyatkina.**

## August 14, 2020

## Forecast of the Withdrawal Date of Indian Summer Monsoon - 2020 from the Central part of India

Daily mean near-surface air temperature till May 4,2020 for EG(red) and NP(blue).Violet and grey lines- past 5-years average for

Delayed monsoon onset in Central India: early warning forecast
May 12, 2020

Early warning: Physicists from Giessen, Potsdam and Tel Aviv forecast "El Niño" for 2020
Nov 04, 2019

Indian monsoon forecast: early warning for risk of flooding in October
Aug 21, 2019

Breaking the rules:

# German modelling to crack monsoon code

n Institute for Climate Impact Research's project, IMD kept in the loop

# 10న రాష్ట్రానికి రుతుపవనాలు

# Eastern Ghats, North Pakistan serve as tipping elements in monsoon prediction

DC CORRESPONDENT
CHENNAI JUNE 9

**The key to their research is in finding the regions where conditions for an occurrence of Indian monsoon originate**

A team of researchers led by the Potsdam Institute for Climate Impact Research (PIK) in Germany has identified two regions — the Eastern Ghats and North Pakistan — that serve as tipping elements in accurately predicting the arrival and departure of southwest monsoon.

As per their research, analysing air temperatures and relative humidity in these areas predict the arrival and departure of the monsoon earlier. "The tipping point is critical to predicting the onset of monsoon. Once it is onset, it's difficult to change," said professor Elena Surovyatkina from Russian Academy of Sciences' Space Research Institute.

"This year, we predicted as early as May 6 that monsoon will hit India on June 13 with plus or minus four days. India Meteorological Department had announced only on May 15 that monsoon will onset over Kerala on June 7," she said.

"We predicted well before 30 days when monsoon would hit central India. It will surely help the farmers in these regions. Based on our method we can predict the withdrawal of monsoon by July 15 based on the observations from the same regions," she added.

The key to their research is in finding the regions where conditions for an occurrence of Indian monsoon originate.

"We can see a patte before the onset of mo soon. We use the precurso not to predict the time b to predict places where the critical transition originates. We take air surface temperature and calculate fluctuation."

"We applied our method for data from 1957 to 2015. Our prediction about the onset of monsoon was 74 per cent successful and withdrawal of monsoon 84 per cent correct. Even for El Nino years our predictions were nearly 60 per cent correct," she said.

When asked whether they had discussions with the IMD about using their new

# తెలంగాణలో రుతురాగం

Telangana Today

Thursday, April 21, 2016 Gulf Times | 21

INDIA |

# Germans develop new method to predict India's monsoon

AFP
Berlin

Climate researchers in Germany said yesterday they had found a way to more accurately predict the Indian monsoon, which could help maximise the subcontinent's food and hydro-power supplies.

# Monsoon likely to hit TS by June 8

According to climate researcher the date of the onset of monsoon is between June 8 and 16

CITY BUREAU
HYDERABAD

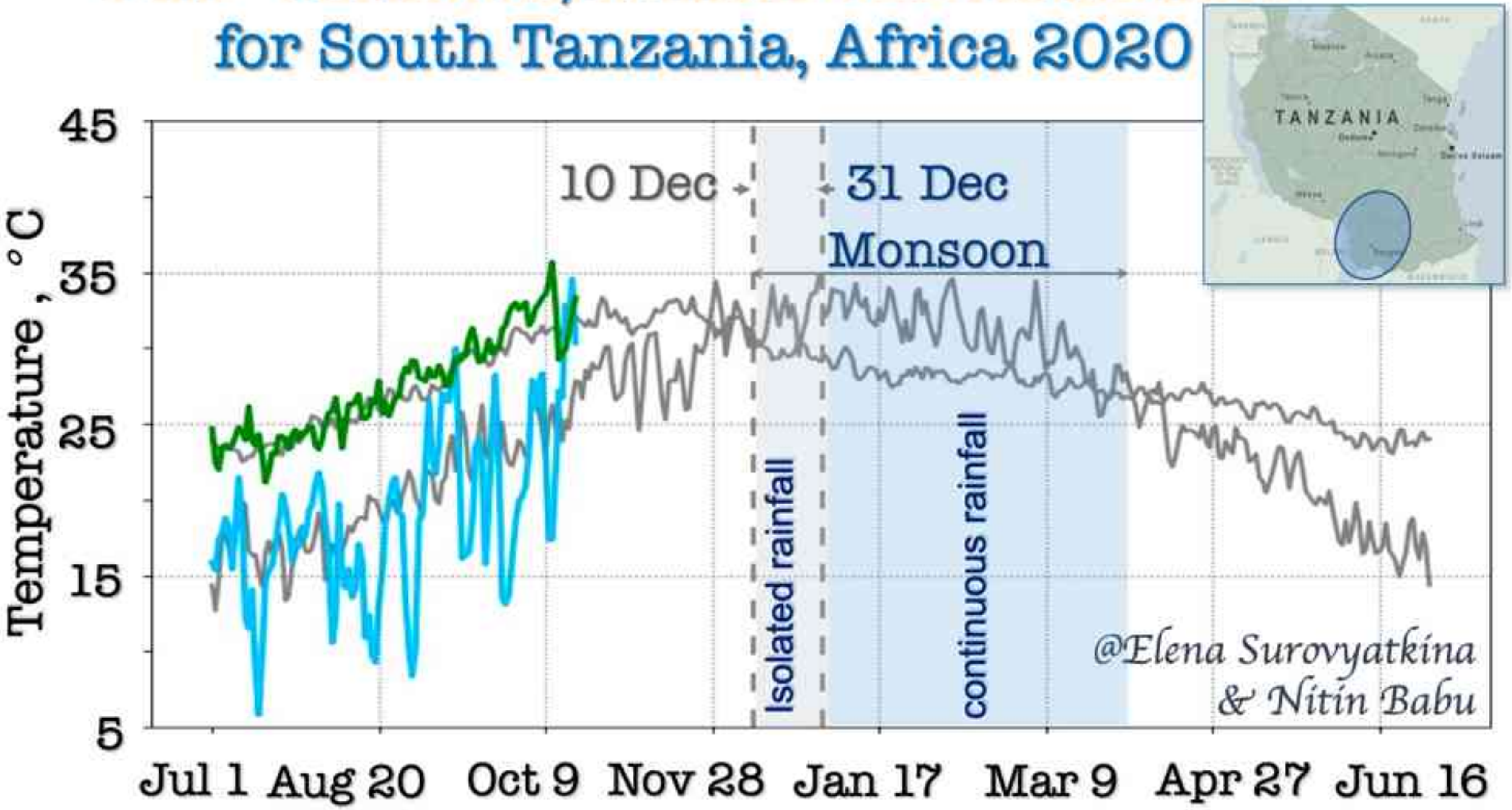
The first monsoon showers to drench Telangana are likely to arrive between June 8 and 16, according to the monsoon forecasting model developed by scientists from Potsdam Institute of Climate Impact Research (PIK), a German government funded research institution.

We are collaborating with IMD and our forecasts complement each other

— ELENA SUROVYATKINA,
CLIMATE RESEARCHER

20 October 2020

# PIK – Monsoon/rainfall season monitor for South Tanzania, Africa 2020

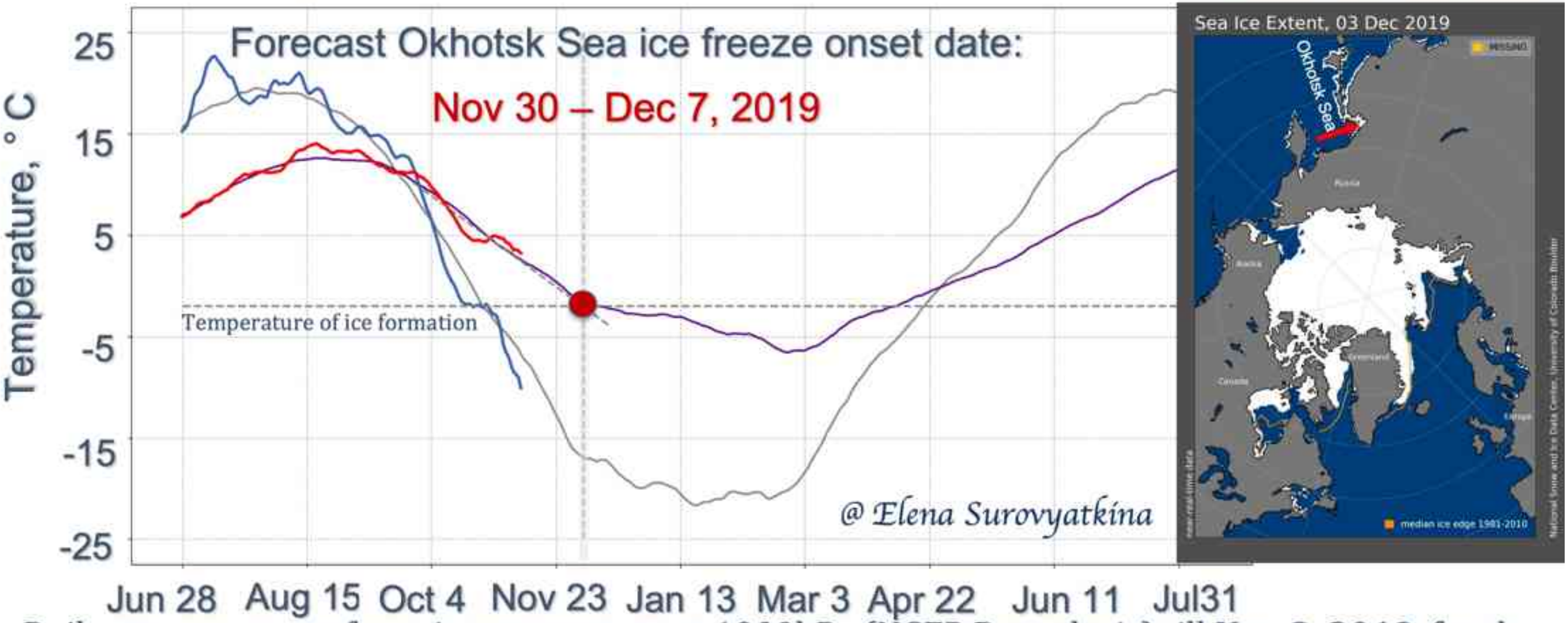


https://www.pik-potsdam.de/en/output/infodesk/forecasting-indian-monsoon

# Forecasting scheme of sea ice advance date

**Abstract ID: 20073**

Evidence from observations



Daily mean near-surface air temperature at 1000hPa (NCEP Reanalysis) till **Nov 8, 2019** for the western (red) and eastern parts (blue). Violet and gray lines - past 19-years average for same regions. The tipping point (red) indicates the critical temperature and the forecasted onset date.

# Current Progress:

I offer the following forecasts both in North and South hemispheres:

- in India: summer monsoon in Central India and Telangana state;
- in Africa: a rainfall season in Tanzania
- in Russia and Japan Sea Ice Season in the Sea of Okhotsk.

# Possible Extensions:

- Eurasia: South Asia, South China, Japan, the Arctic Circle;
- Africa: Ethiopia, Congo;
- South and North America.

# Conclusion

The new methodology offers the following advances:

1. Predicting the date of the upcoming monsoon onset for 40 days in advance, that is unprecedentedly early.
2. Forecasting withdrawal date for 70 days in advance, and it is the only one available withdrawal forecast in India.
3. The applicability of the methodology is not limited by specific location; it works for different parts of India, Africa and South America.

The six years tests (2016-2021) show successful results.

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Thanks my co-authors